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N64-16707

ER-5212) OTS:

(NASA CR-55830; Code 1

RESEARCH ON THE

VORTEX MHD POWER GENERATOR

THIRD QUARTERLY PROGRESS REPORT

W. C. Davis et al

January 1963 13p

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Thompson Ramo Wooldridge Inc., Cleveland, Ohio

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(NASA Contract No. NAS3-2526)

RQT-7864

TAPCO

A Division of

Thompson Ramo Wooldridge Inc.

Subject:	Third Quarterly Progress Report, January 1963
Contract No.:	NAS3-2526
TRW Project No.:	512-009604-08
Title:	Research on the Vortex MHD Power Generator
Contributors:	W. C. Davis
	A. C. Eckert
	W. F. Wade

W. C. Davis

W. C. Davis
Senior Engineering Specialist

R. T. Craig

R. T. Craig
Project Manager

I. INTRODUCTION

This report summarizes the efforts during the third quarter of a one-year research program, whose principal objective is the demonstration of feasibility and advancement of the vortex MHD power generator concept.

Experimental efforts have concentrated on providing instrumentation for the vortex MHD generator tests and also for the vortex chamber apparatus to be employed in a detailed study of turbulent vortex flow.

Analytical efforts included the undertaking of a study to apply recent theories of nonequilibrium and Hall effects to the vortex MHD generator. The possibility of controlling the Hall currents by cancellation with azimuthal currents induced by the radial component of fluid flow also is being considered.

II. SUMMARY

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The experimental model of the vortex MHD generator and its auxiliary apparatus, including instrumentation, have been prepared for initial testing and evaluation. A device for seeding the plasma by atomizing and injecting cesium hydroxide into the arc heated argon was developed.

A gas dilution calorimeter was constructed for the purpose of determining enthalpy levels of the plasma supplied to and discharging from the vortex generator. Its operation was successful in a trial test.

The water-cooled copper nozzles developed for the vortex generator were operated under maximum power conditions and discharging into the atmosphere. No deterioration of the nozzles was evidenced and the operation otherwise appeared satisfactory.

Instrumentation for the vortex flow apparatus was completed. Initial operation of this facility revealed some minor problems which have been, or soon will be, corrected. The performance of the vortex chamber device is expected to be satisfactory.

A preliminary study of Hall current suppression in the vortex MHD generator revealed the conditions under which Hall effects can be usefully employed or, on the other hand, be diminished in their degrading influence.

AUTHOR

III. ITEMS OF PROGRESS

1. Vortex Generator Experiments

Vortex Generator Model. The experimental model of the vortex MHD generator was assembled with the necessary internal electrical connections and internal instrumentation. The electrical connections consist of two tantalum strips, each resistance welded to the outer tungsten electrode and then bolted to the stainless steel generator frame. Difficulties encountered in resistance welding were overcome primarily by cleaning the surfaces to be joined with a hydroxide solution and using well prepared welding electrodes having a good surface finish to prevent electrode-to-work piece sticking. No intermediate foil was employed as is often the case for joining refractory metals because of the relatively low melting temperatures of the resulting bond. The weldments produced seemed to be structurally adequate although not to the same degree that is possible with non-refractory metals. The real proof of adequacy must await the results of the initial generator operation.

The internal instrumentation of the generator include: nozzle upstream static and back pressure ports; radiation shielded W - W/.26 Re thermocouples located on the outer surface of the tungsten electrode ring; C/A thermocouples mounted at the interface of the MgO and ZrO_2 sidewall insulators and also at the interface between the ZrO_2 insulator and soft iron sidewall cover; C/A thermocouples cemented into the inside surface of the generator frame; and finally W - W/.26 Re thermocouples located in the flanged section of the graphite exhaust tubes and adjacent to the tungsten overlay which forms an electrode surface. With the exception of the latter, all of the thermocouples are located such that radial and azimuthal variations in temperature can be determined as well as the heat flux or thermal conductances of the various insulators. Other thermocouples have been installed for purposes of measuring the temperature rise of the air streams which externally cool the generator.

The various gas metering systems required for a generator test were installed and calibrated by a laminar flow meter of 0.5 per cent accuracy. The primary metering elements are choked nozzles which are furnished with the necessary temperature and pressure gages. These systems provide the metering and control of primary and secondary (for seed injection) argon flows to the indicidual arc heaters and nozzles, and air cooling flows for the generator sidewalls and periphery.

A water-cooled copper nozzle of the vortex generator was tested by operating it with maximum arc heater input power of 60 KW and discharging into the atmosphere. The water temperature rise was 25°F for 3.2 gpm flowing under a head of 45 psid. Heat dissipation in the nozzle was thus 12 KW. Operation under these conditions for four minutes did not produce any deterioration of the nozzle. Consequently, satisfactory operation of the nozzle can be expected for generator operation.

A seed injection mechanism was developed and operated for trial purposes by discharging seed solutions, consisting of concentrated aqueous solutions of cesium hydroxide, into the atmosphere. The device consists of an arrangement whereby two diametrically opposed streams of seed solution are directed perpendicularly into a high velocity jet of argon. The resulting atomized spray is then ducted into the generator nozzle mixing chamber adjacent to the front electrode orifice of an arc heater. Subsequent mixing of the impinging spray and arc heated argon produce the required plasma. Operation of the injection mechanism in conjunction with the generator nozzle gave no visible indication of distortion of the nozzle jet.

Modifications have been completed which adapt the previously used generator magnet structure to the more extensive requirements of the new generator. The principal change was the incorporation of coolant passages, for control of the generator sidewall heat flux, into the magnet pole caps. Measurement of the field intensity produced with the correct generator gap spacing indicated a field intensity of 6,000 gauss at incipient saturation and a maximum deviation of five per cent from the mean field strength throughout the entire generator cavity volume. Fields of 8,000 gauss were obtained at considerably greater coil currents but only could be maintained for short periods (up to one minute) before excessive coil heating occurred. The limitation in field strength is caused primarily by insufficient core area and consequently iron saturation.

Generator External Instrumentation. The control and data recording equipment required for testing the generator has been installed and checked out. Figure 1 shows this equipment located in the generator test area. Parameters which will be indicated and recorded include the generated voltage and current, applied magnetic field, and appropirate generator component temperatures. The data recorders include both high speed and low speed print out equipment.

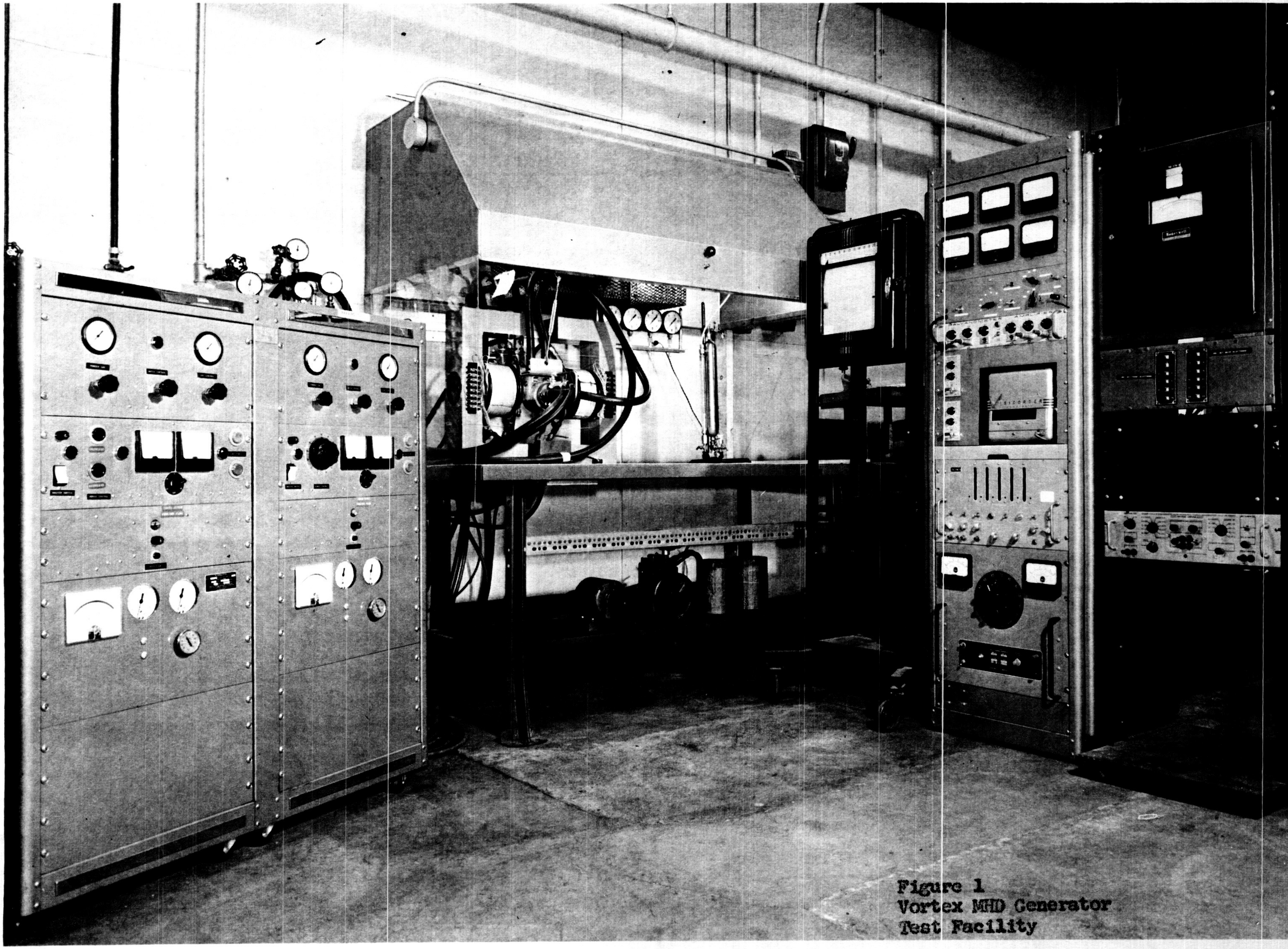

Figure 1
Vortex MHD Generator
Test Facility

A preliminary operational check was performed with the gas dilution calorimeter intended for the determination of plasma enthalpy. Its performance was very satisfactory from the standpoint of both structural capability and thorough mixing of gas streams. A typical result indicated a conversion efficiency of the arc heater and nozzle combination of 63 per cent for an input power of 20 KW. In this case, the mean argon jet temperature of 5300°F was subsequently reduced to 1500°F by dilution of the argon with nitrogen.

2. Hydrodynamics of the Jet-Driven Vortex

Experimental Program. The cold-gas vortex chamber model was instrumented, pressure and leak tested, silenced, and several preliminary runs were made to check the accuracy of the total pressure probe.

Initial instrumentation for the vortex model consists of a dial thermometer to measure upstream stagnation temperature, an upstream pressure tap and a throat pressure tap on each of the four nozzles to measure nozzle flow rates, twelve static pressure taps spaced 0.125 inch apart on a radial line on one side-wall of the vortex chamber, and a total pressure probe with two side tubes for flow direction indication. These instruments have all been installed and are shown in three photographs of the vortex model, assembled with two inlet nozzles and two dummy nozzles, Figures 2, 3, and 4. The probe traversing rig and the shank of the directional total pressure probe are visible in Figure 2, and Figure 3 shows the manometer lines and connections to the twelve static pressure taps. Figure 4 shows the vortex model with the probing rig removed; the interior of the vortex chamber and the tip of the total pressure probe may be seen.

The vortex model was pressure and leak tested by gradually increasing the inlet pressure to the nozzles, and checking for air leaks. Leakage was found to be no problem, the combination of circular and linear O-rings used in the model provides a good seal; however, at high pressures (80-90 psig) several of the nozzles and one of the cast epoxy-resin transition pieces ruptured. These failures were rather gentle, consisting of a crack opening up at a glued joint, thus relieving the pressure; no shattering or fragmentation of the parts was experienced. The failures were repaired by regluing and wrapping the parts with fiberglass cloth saturated with epoxy resin. In addition, larger flanges of epoxy resin were cast around the downstream ends of the transition pieces and the mating upstream ends of the nozzles, to provide additional strength. These modifications are all clearly visible in Figures 2, 3, and 4.

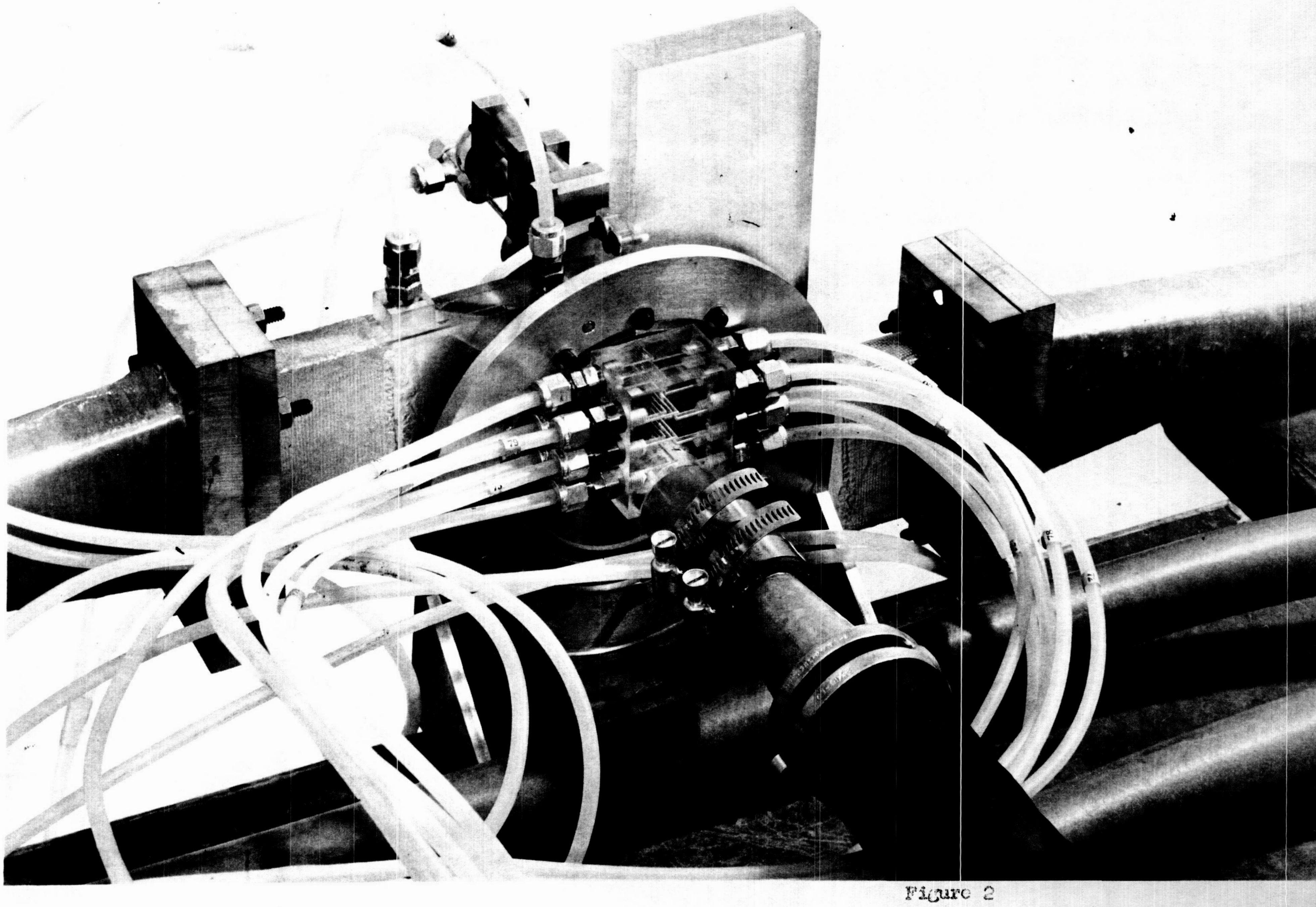

Figure 2
Cold-Gas Vortex Chamber

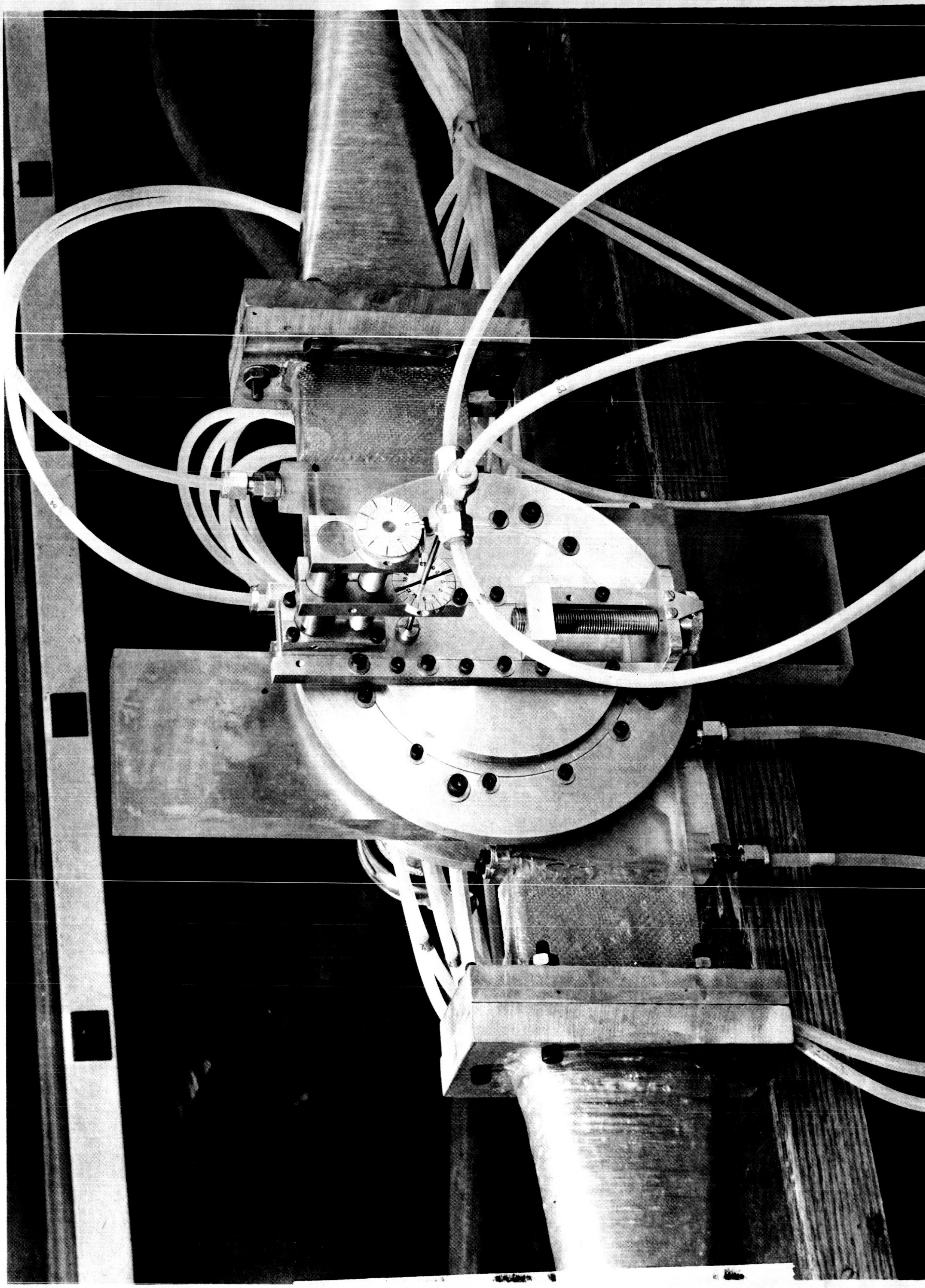

Figure 3
Vortex Chamber, Rear View

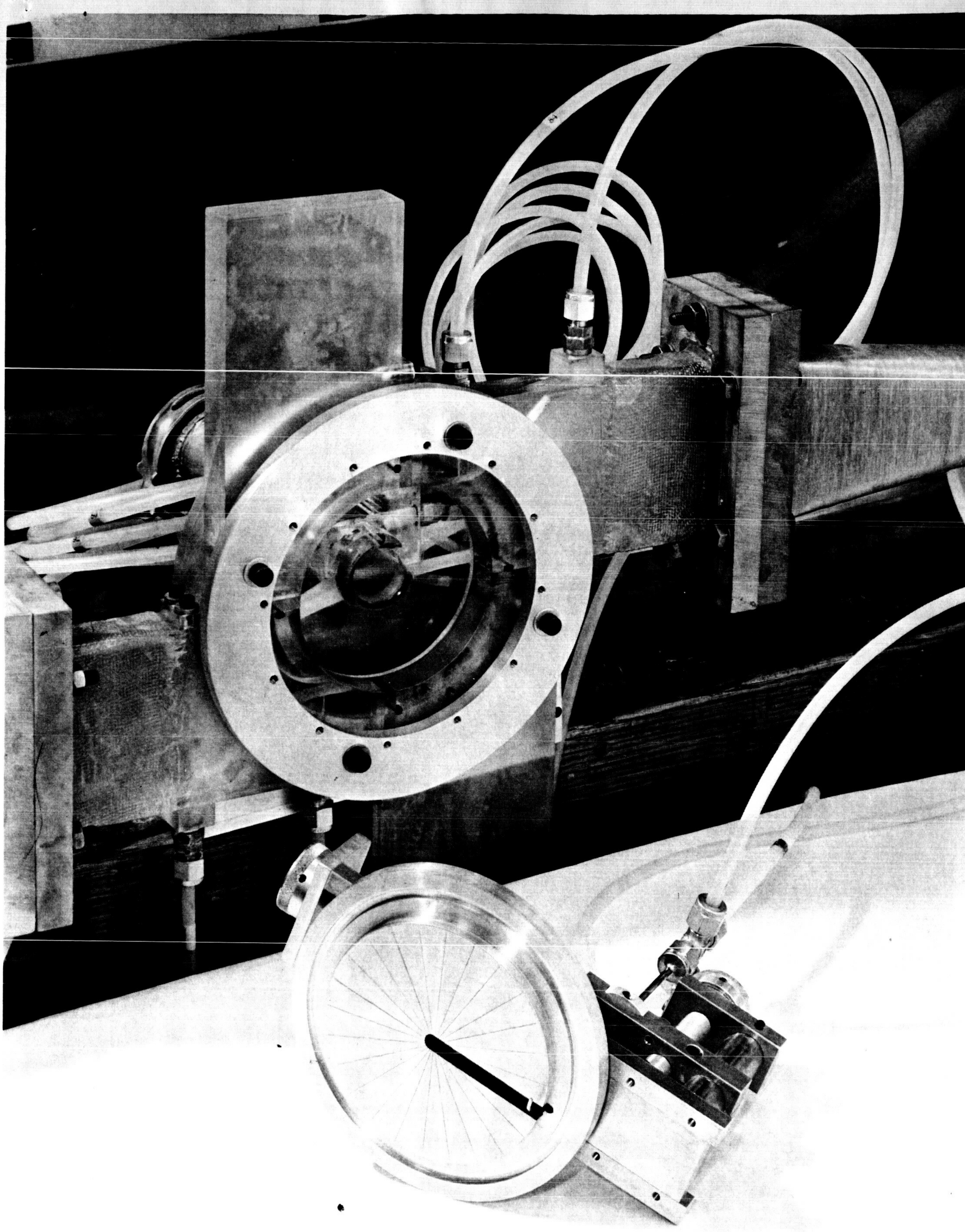

Figure 4
Vortex Chamber, Disassembled

Noise was an additional problem. With a low flow rate through the chamber, the device was essentially silent, but as the flow was increased, a whistle began to develop which eventually changed to a scream, of a high enough intensity to be painful to everyone in the area, even when earplugs were used. The noise was found to come from the downstream end of the vortex chamber exit-tube, the whistle being due to an "organ-pipe" resonance of the exit tube, and the scream to the interaction of turbulent flow noise with the whistle. The scream was eliminated by placing a fine-mesh (105 wires per linear inch), high-porosity (47 per cent open) screen over the exit tube opening, and the whistle was eliminated by extending the exit tube with a long straight pipe or a diffuser and straight pipe (as shown in Figure 3). At present, the only noise made by the vortex model is the usual high-frequency flow noise.

Several preliminary test runs were made to check the accuracy of the total pressure probe. Two problems arose which are now being solved. First, the positive displacement compressor, used as the main air supply, does not maintain a constant upstream pressure. Because of poor compressor regulation, the vortex chamber pressure varies 2 to 10 psi. The easiest solution is to draw off the full output of the compressor so that it runs continuously; a bleed line with muffler is now being installed which will allow the excess air to be exhausted back to the atmosphere. Second, the radial pressure gradient in the vortex chamber is stronger than expected, leading to false flow-direction indications from the probe. This effect will be reduced by reducing the distance between the directional tubes of the probe, but will ultimately have to be corrected by calculation while taking data.

3. Hall Current Suppression and Nonequilibrium Ionization

Analytical Studies. Vortex MHD flows constrained such as to produce a vanishing azimuthal component of current are being studied. Modivation for this study is provided by the possibility and desireability that the Hall potential due to the tangential velocity can actually be used to reduce azimuthal currents, while the Hall potential due to the radial velocity can be made to enhance the radial flow of current. Furthermore, the reduction in effective plasma conductivity due to Hall effects can be minimized. Consider the expressions for radial and azimuthal current:

$$j_r = \frac{\sigma}{1 + (\omega\tau)^2} \left[E_r + vB + (\omega\tau)\, uB \right] ,$$

$$j_\theta = \frac{\sigma}{1 + (\omega\tau)^2} \left[-uB + (\omega\tau)\,(E_r + vB) \right]$$

If, for example, the azimuthal current can be made to vanish by imposing the condition

$$uB = (\omega\tau)\ (E_r + vB)$$

then the expression for radial current becomes simply

$$j_r = \sigma\ (E_r + vB)$$

without the usual reduction in effective conductivity at significant $(\omega\tau)$ typical of linear MHD generators with continuous electrodes.

The above condition may also be written in the form

$$u/v = (\omega\tau)\ (1 - K)$$

where $K \equiv -E_r/vB$, the local generator coefficient which is in general a function of position. This condition, as well as the equation for power density in the MHD generator, namely

$$P/V = \sigma_{eff}\ (vB)^2\ (1 - K)\ K$$

must be considered for their overall contribution to generator performance. Other aspects of this condition, which will be considered in future efforts, include the requirement that the radial mass flow and current directions are identical and also that the degree of plasma ionization within the vortex volume is a constant with respect to position. The former requirement implies that the electrode adjacent to the exhaust gases serves as a cathode or electron emitter. Since this is the cooler of the two electrodes, emission limitations may be serious. The latter requirement must be carefully examined keeping in mind the phenomena of nonequilibrium ionization which occurs for circumstances in which the electron gas may obtain, in the pressure of an electric field, an average energy in excess of the energy of the atoms and ions.

IV. INTERPRETATION OF RESULTS AND CONCLUSION

All of the necessary auxiliary apparatus and instrumentation required in the vortex MHD generator test program have been completed and checked out. Initial testing of the generator will be undertaken with single jet operation and followed shortly by dual jet operation.

The vortex chamber installation has been successfully operated after some minor problems were corrected. In particular, its design concept appears to be quite satisfactory. The pseudo-laminar flow analysis for turbulent vortex flow, which was developed earlier in this program, will be correlated with the forthcoming results of the vortex chamber experiments.

Means of suppressing Hall effects in the vortex MHD generator have been indicated. The various ramifications and limits of this suppression will be studied further in the continuing effort.